# Wide-Area Persistent Energy-Efficient Maritime Sensing

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## LONG-TERM GOALS

The goal of this project is persistent maritime sensing by energy-efficient collection and telemetry of multichannel data from sensors distributed over a wide area. The endurance and coverage area of current maritime sensing methods are fundamentally limited by the energy used for communication, navigation, computation, and/or propulsion. Our concept overcomes these limitations by eliminating the need for RF electronics or navigational hardware at the sensors and instead uses a stand-off radar for sensor localization and data exfiltration (SLADE). The approach for persistent energy-efficient maritime sensing (PEEMS) consumes only milliwatts of power on the sensing package itself. This dramatic reduction in power consumption is achieved by using quasi-passive differential radar-cross-section (DRCS) signaling to telemeter sensor data to a ship or shore-based collection point. Meanwhile, radar signal processing provides localization of the nodes so that multichannel sensor data can be processed coherently or incoherently to achieve synoptic maritime sensing over a wide area.

## OBJECTIVES

1) Development of a differential binary phase shift keying (D-BPSK) line code and other codes that allow for DRCS communications without the need to have clocks synchronized between the radar and the passively operating node (PON).
2) Automatic range localization of a passively operating node using a preamble D-BPSK signaling DRCS sequence.
3) Analysis of fundamental limits and tradeoffs between localization accuracy and communication rate.
4) Real-time demonstration of data exfiltration from a node at 10 kbps using an indoor hardware brass-board system with autonomous clock synchronization for target localization.
5) Separation of data sequences from 2 DRCS nodes in an outdoor multipath environment at ranges up to 50 meters.
6) Design and fabrication of custom circuit board for DRCS signaling.

## APPROACH

Modulated backscatter offers the prospect of extremely low power consumption for telemetry uplink from wireless devices. Backscatter communication relies on an incident electromagnetic signal for the RF carrier and conveys information with controlled reflections of this signal. Since backscatter devices do not need to generate their own RF carrier, they need not contain potentially complex and power-hungry local oscillator and transmit power amplifier; thus enabling low-power, low-cost communication links.

A simplified block diagram of a PEEMS signal processing chain is shown in Figure 1. The essential blocks include generation of an FMCW chirp waveform, transmission to the SLADE node, DRCS modulation of the backscattered radar waveform at a rate of $1/T_b$ , corresponding the signaling rate (e.g. bit rate), propagation back to the radar, de-chirping, ground clutter suppression via moving target indicator (MTI) processing, matched filtering, and threshold detection to recover the transmitted digital data. The system is "quasi-passive" since a battery is required to operate the pre-amplifier(s), ADC, and micro-controller, although there is no RF transmit or receive electronics.

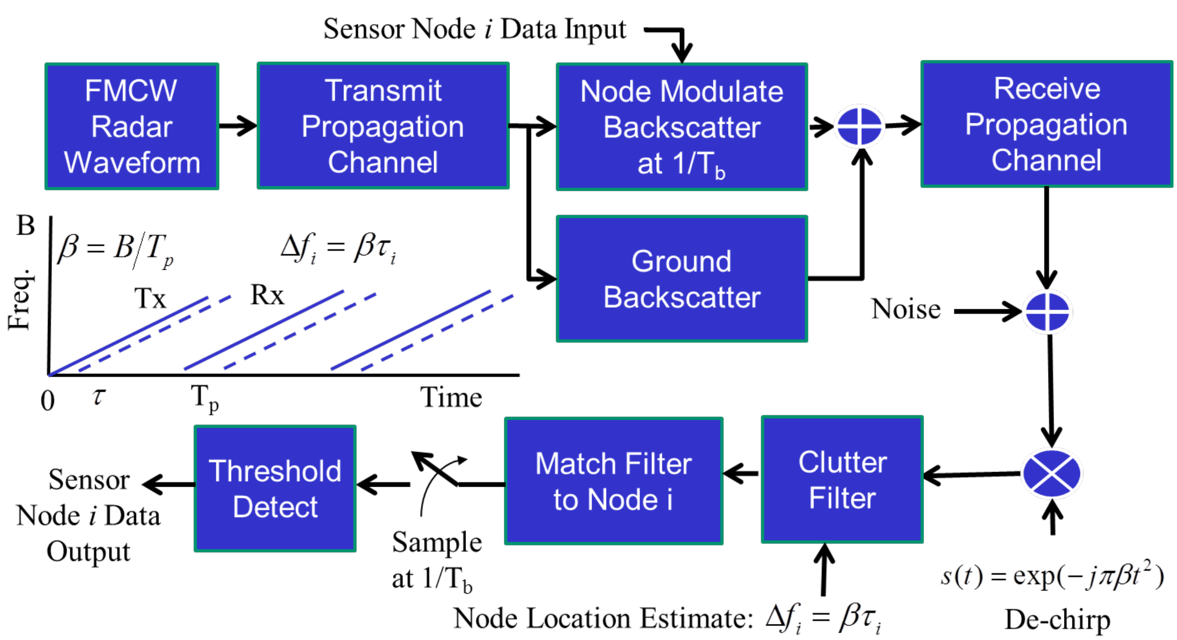


***Figure 1: Simplified Signal Processing Chain for PEEMS***

Itay Cnaan-On is a PhD student at Duke who is primarily working on the signal processing and the tradeoff between localization accuracy and communication rate, looking at both the theoretical limits as well as practical achievable processing. Stewart Thomas was a post-doctoral scholar at Duke who primarily worked on the design of the backscatter node as well as setting up a working system that demonstrated data exfiltration and node localization. Matt Reynolds, Lefteris Kampianakis, and Andreas Pedrosse-Engel at UW designed and tested a Software Defined Radar testbed as well as an Arduino-based backscatter node that can be used for field trials on Lake Washington in Seattle.

## WORK COMPLETED

1) Development of standalone radar hardware based on a software-defined radio platform.
2) Development of a standalone Arduino-based backscatter node.
3) Analysis of the limits of the tradeoff between node localization accuracy and communication rate.
4) Live demonstration of exfiltration of temperature data using TAG backscatter hardware attached to a temperature sensor and an LFM-based radar transmitter/receiver.

## RESULTS

To validate the approach, a brass-board bistatic S-band radar and accompanying backscatter sensor nodes were constructed. The digital processing is as described in Figure 1 above. The radar transmits at a center frequency of 2.45 GHz with a bandwidth of 40 MHz and a chirp rate of 5 kHz. The semi-passive backscatter nodes were realized using a Hittite HMC241LP3 RF switch and an L-COM HG2414P 14 dBi S-Band patch antenna. The baseband data is supplied by a temperature sensor and a hard-coded preamble sequence is used for node localization. The system setup is shown in Figure 2.

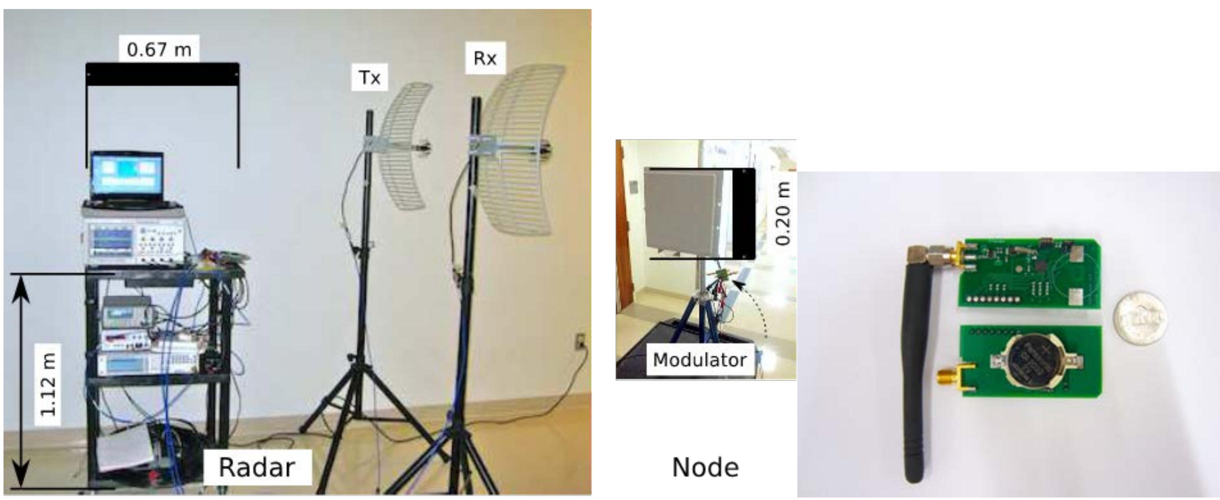


***Figure 2: Experimental setup. The radar hardware is shown on the left, including waveform generator and transmit and receive high-gain antennas. The node hardware is shown on the right including a closeup of the node board with a US nickel for scale reference.***

Experimental results with three node uplinks at approximately 15, 50, and 130 meters in an outdoor environment are shown in Figure 3. The plot shows an amplitude-delay-Doppler (ARD) surface of the returned signal from each node. The clutter (static returns from the ground and nearby buildings) has been filtered using MTI processing. The information conveyed by the three nodes is seen to be spread in both delay and Doppler. The signal is centered in range (i.e., delay) around the actual range of the node. The Doppler spread of the information allows it to pass through the MTI clutter filter.

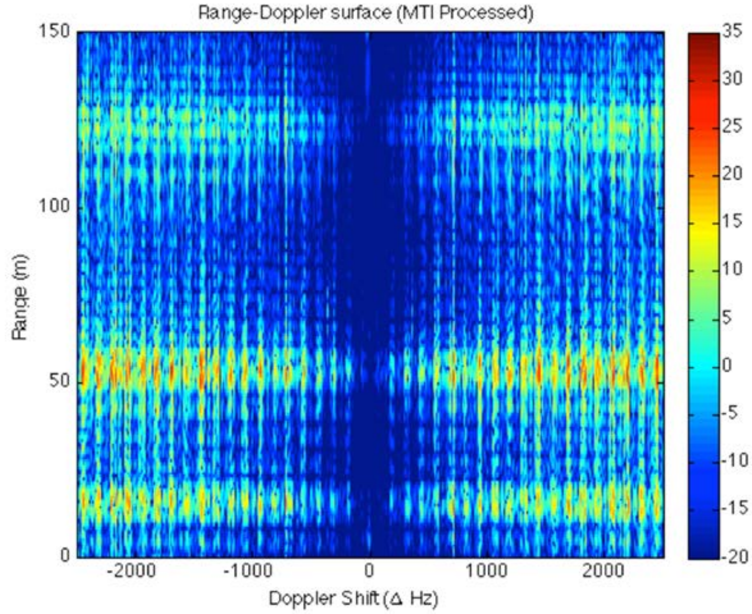


***Figure 3: Measured spectrum of received signal after clutter filtering, here shown as a radar delay-Doppler surface. The clutter filtering is a simple MTI filter. The spectrum of each node is clearly seen at a distance of approximately 15m, 50m, and 130m.***

We have also developed testbed hardware for flexible testing in diverse environements. Figure 4 shows an Arduino-based node that can modulate radar backscatter with data received from a sensor using a low-power Arduino Nano processor. Figure 5 shows a block diagram of the software-defined radar transmitter/receiver. The waveform is generated from a laptop running MATLAB and is sent through a GNURadio pipeline to a USRP B210 board. The USRP transmits the waveform over the air and receives the returns from the modulating node. It is planned to use this testbed to collect on the open water to confirm operation at sea.

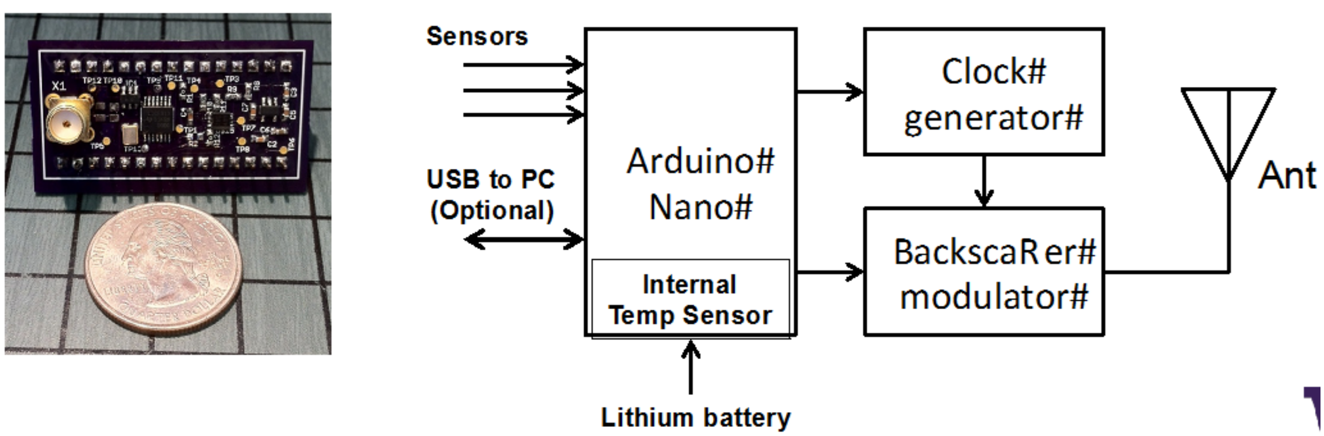


***Figure 4: Block diagram and picture of the Arduino-based backscatter node***

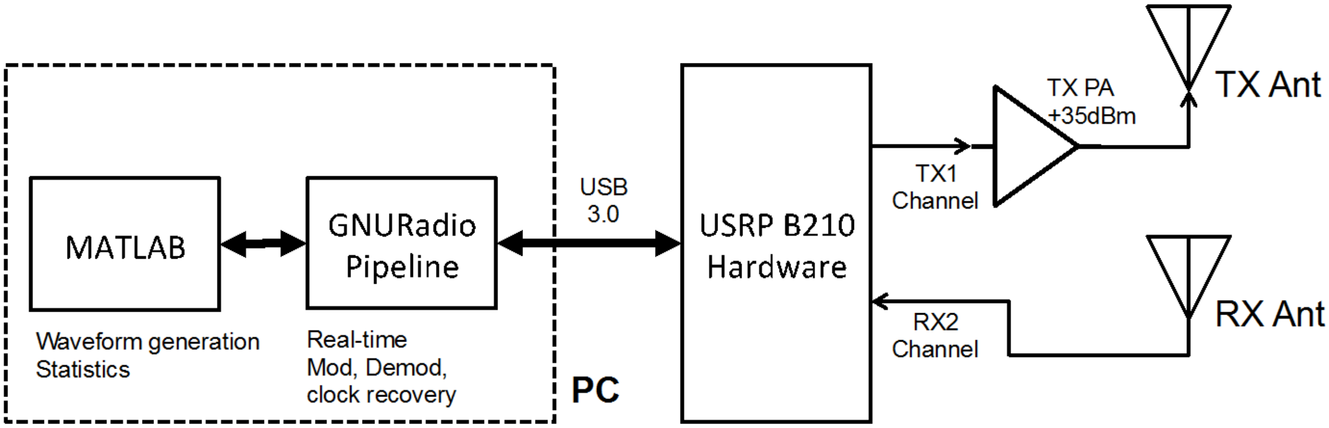


*Figure 5: Block diagram of the software-defined radar hardware*

## IMPACT/APPLICATIONS

This technology for maritime sensing, using sensors distributed over several tens of miles operating with an endurance of a year or more, could be applied to a variety of Navy applications including ship self-protection, anti-submarine warfare, synoptic oceanographic field measurement, and harbor security. In particular, the reduction in cost achieved by greatly reducing node-level RF electronics or navigational hardware could enable entirely new concepts for maritime sensing. Finally, sensor tamper-proofing is achieved because sensitive data is not stored on the node and resistance to jamming or interception can be provided by the use of wideband spread-spectrum radar waveforms.

## RELATED PROJECTS

None

## PUBLICATIONS

1. Itay Cnaan-On, Stewart J. Thomas, J. Krolik, M. Reynolds, "Multichannel Backscatter Communication and Ranging for Distributed Sensing with an FMCW Radar", submitted to IEEE Transactions on Microwave Theory and Techniques, revised manuscript submitted July, 2014.

## CURRENT PERSONNEL SUPPORTED ON THIS GRANT

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